

OPTIMIZATION OF SUSPENDED SOLIDS REMOVAL
FROM COAL-ASH LADEN WASTEWATERS

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MASTERS PROJECT

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ABSTRACT

Wastewater resulting from the drawing down of ash from coal-fired boilers contains a significantly high concentration of suspended solids requiring treatment prior to release into sanitation lines for treatment at municipal wastewater treatment plants. As an example, the steam plant at the Naval Amphibious Base Little Creek in Norfolk, Virginia is experiencing high surcharges from the Hampton Roads Sanitation District (HRSD) for the high concentration of suspended solids in their wastewater. At present, there are no mechanisms in place to pre-treat this wastewater prior to its discharge into HRSD.

The purpose of this project is to analyze the effectiveness of various coagulant aids in the removal of suspended solids from the ash-laden wastewater. In addition, the effectiveness of an anionic polymer in response to changes in pH, velocity gradients of flocculation, and various top/bottom ash water mixtures was analyzed.

INTRODUCTION

In January 1991, the Old Dominion University's Research Foundation was subcontracted by URS Consultants to conduct wastewater treatability studies on wastewater samples obtained from the coal-fired steam plant at the Naval Amphibious Base Little Creek, Norfolk, Virginia. The location of the steam plant

is shown in Figure 1. URS Consultants was contracted by the Naval Amphibious Base Little Creek to conduct wastewater treatability studies on wastewater from the ash-silo at the steamplant. The Naval Amphibious Base Little Creek has been experiencing a high level of suspended solids in its wastewater and consequently, the base is paying some very severe surcharges to the Hampton Roads Sanitation District (HRSB) to treat the wastewaters from various outfalls. Through some exhaustive field investigations by URS Consultants and Little Creek personnel, it was determined that the coal ash present in the ash-silo waste water is the primary constituent suspended in the water and thus is causing the problem, at least for one lift station evaluated. The wastewater from the ash-silo is the result of draw-down operations conducted on the active boilers during each 8-hour shift at the steam plant. The ashes are removed first from the boiler by the use of mechanical stokers and fall into a grit chamber. Then, the top ashes (fly-ash) are pulled through the use of domestic water being sprayed into the chamber and then approximately 15 minutes later, the bottom ashes are pulled. The top and bottom ash removed is pumped with water into a centrifugal separator which removes the large ash particles from the water and then allows the wastewater to flow by gravity to the sanitary sewer system. The larger ash particles fall into the silo which is emptied once a day and hauled to a sanitary landfill by a commercial contractor.

COAGULATION AND SEDIMENTATION

Before the results of the analysis can be presented, it is

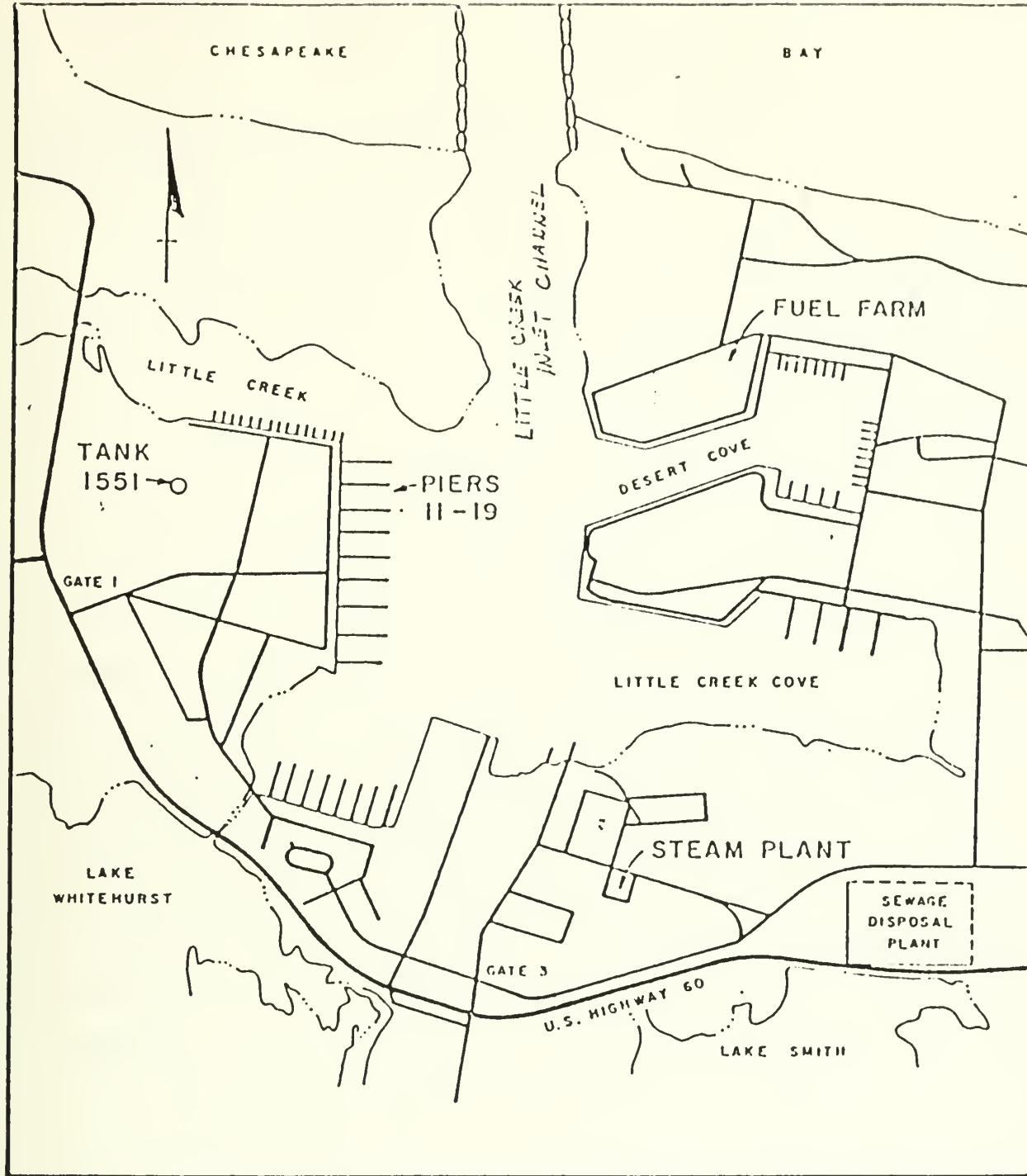


Figure 1: Locations of Fuel Farm, Steam Plant, Tank 1551, and Piers 11-19 at the Little Creek Naval Amphibious Base.

necessary to first discuss the concepts behind coagulation and sedimentation.

Virtually all water sources contain perceptible turbidity. As the terminal settling velocity of particles in suspension is related to the particle size, it is obvious that plain sedimentation will not be very efficient for the smaller suspended solids. Therefore, the agglomeration of particles into groups, increasing the effective size and therefore the settling velocities, is possible in some instances. This process of agglomeration or aggregation is termed coagulation and is considered as involving two separate and distinct steps: (1) particle transport to effect interparticle contact, and (2) particle destabilization to permit attachment when contact occurs. Theories of particle transport are based on fluid and particle mechanics; theories of particle destabilization are based on colloid and surface chemistry. The design of structures and flocculation equipment for a coagulation process is influenced by a consideration of interparticle contacts; the selection of the type and dosage of coagulant is based on a consideration of particle destabilization. The design of the overall coagulation process must provide for both of these steps.

Particles in the colloidal size range, however, possess certain properties that prevent agglomeration. Surface waters with turbidity resulting from colloidal particles cannot be clarified without special treatment.

Colloidal suspensions that do not agglomerate naturally are called stable. The most important factor contributing to the

stability of colloidal suspensions is the excessively large surface-to-volume ratio resulting from their very small size. Surface phenomena predominate over mass phenomena. The most important surface phenomena is the accumulation of electrical charges at the particle surface. (2) Molecular arrangement within crystals, loss of atoms due to abrasion of the surfaces, or other factors may result in the surfaces being charged.

Ions contained in the water near the colloid will be affected by the charged surface. A negatively charged colloid with a possible configuration of ions around it is shown in Figure 2. The first layer of cations attracted to the negatively charged surface is "bound" to the colloid and will travel to it, should displacement of the colloid relative to the water occur. Other ions in the vicinity of the colloid arrange themselves as shown, with greater concentrations of positive, or counter, ions being closer to the colloidal surface. The arrangement produces a net charge that is strongest at the boundary layer and decreases exponentially with distance from the colloid.

When two colloids come in close proximity there are two forces acting on them. The electrostatic potential created by the "halo" of counter ions surrounding each colloid reacts to repel the particles, thus preventing contact. The second force, and attraction force called the van der Waals force, supports contact. This force is inversely proportional to the sixth power of the distance between the particles and also decays exponentially with distance. It decreases more rapidly than the electrostatic potential, but is stronger at close distances. The sum of the two

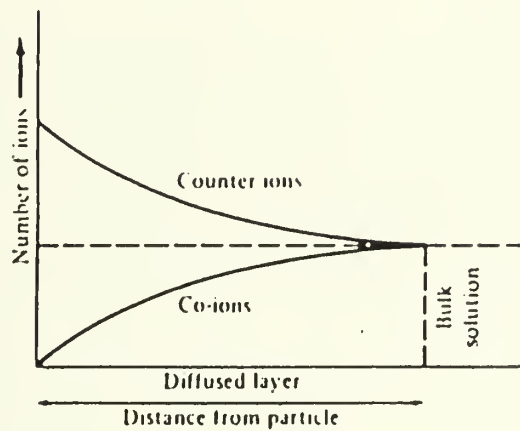
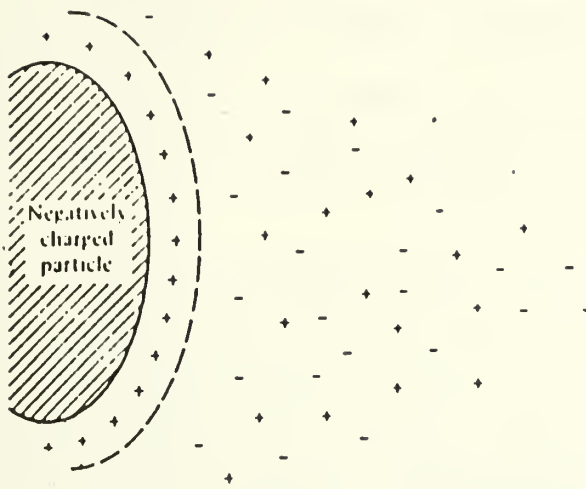


FIGURE 2: Charge system in a colloidal suspension

Source: H. S. Peavy, D. R. Rowe, and G. Tchobanoglous,
ENVIRONMENTAL ENGINEERING, McGraw-Hill, New York, 1985

forces as they relate to one colloid in close proximity to another is illustrated in Figure 3. As noted in the figure, the net force is repulsive at greater distances and becomes attractive only after passing through a maximum net repulsive force, called the energy barrier, at some distance between colloids. Once the force becomes attractive, contact between the particles takes place.

A means of overcoming the energy barrier must be available before agglomeration of particles can occur. Brownian movement, the random movement of smaller colloids because of molecular bombardment, may produce enough momentum for particles to overcome the energy barrier and thus collide. Mechanical agitation of the water may impart enough momentum to larger particles to move them across the energy barrier. These processes are too slow, however, to be efficient in water purification, and neither results in collisions of medium-sized colloids. Thus, other means of agglomeration must be used. In water purification this is generally accomplished by chemically coagulating the colloids into clusters, or flocs, which are large enough to be removed by gravity settling.

Chemical coagulation can be accomplished by the addition of trivalent metallic salts such as $Al_2(SO_4)_3$ (aluminum sulfate) or $FeCl_3$ (ferric chloride). Other coagulant aids exist such as silica, cationic polymers, and anionic polymers. Although the exact method by which coagulation is accomplished cannot be determined, four mechanisms are thought to occur to destabilize colloids. (5) These include ionic or double layer compression,

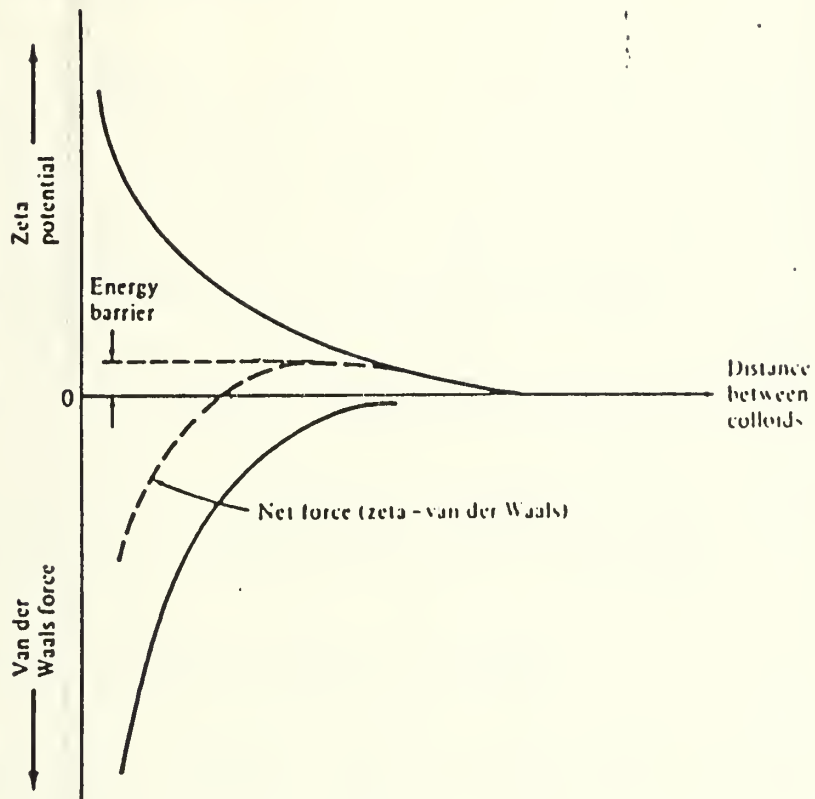


FIGURE 3: Force fields between colloids of like charges

Source: H. S. Peavy, D. R. Rowe, and G. Tchobanoglous,
ENVIRONMENTAL ENGINEERING, McGraw-Hill, New York, 1985

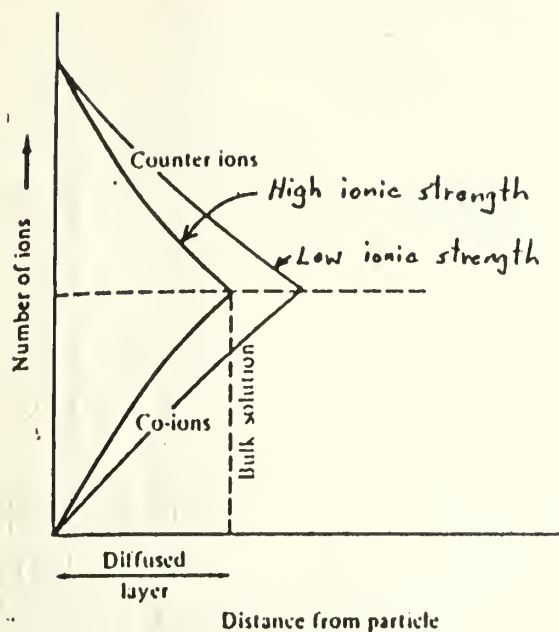
adsorption and charge neutralization, entrapment in a flocculant mass, and adsorption and interparticle bridging.

Double layer compression:

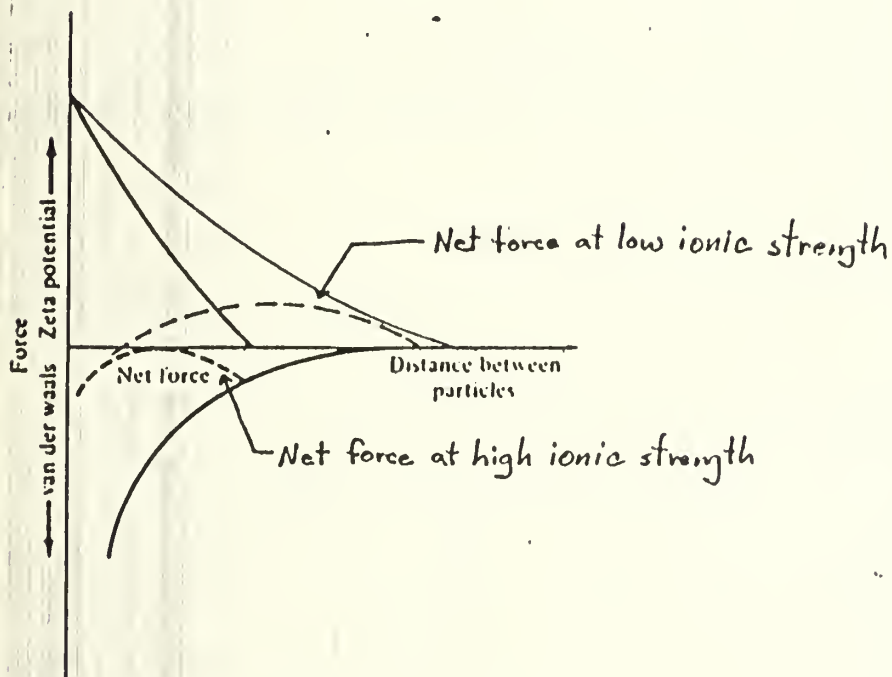
The quantity of ions in the water surrounding a colloid has an effect on the decay function of the electrostatic potential. (1) As illustrated in Figure 4 a high ionic concentration compresses the layers composed predominantly of counter ions toward the surface of the colloid. If this layer is sufficiently compressed, the the van der Waals force will be predominant across the entire area of influence, so that the net force will be attractive and no energy barriers will exist.

Adsorption and Charge Neutralization

The nature, rather than the quantity, of the ions is of prime importance in the theory of adsorption and charge neutralization. Metal hydroxides and synthetic organic polymers (polymers) can be used to adsorb on particle surfaces to reduce the negative charges on the particle surface. This reduction in surface charge thereby reduces the electric potential, or energy needed to bring a like-charged particle to a particular distance from the charged surface (i.e., a reduction in the repulsive forces of the particle). (1) This process could in effect neutralize the surface charge of the particle. Once the surface charge has been neutralized, the ionic cloud, or double layer, dissipates and the electrostatic potential disappears so the contact occurs



(a)



(b)

FIGURE 4: Ionic Compression (a) Reduction of thickness in diffused layer; (b) reduction of net force

Source: H. S. Peavy, D. R. Rowe, and G. Tchobanoglous, ENVIRONMENTAL ENGINEERING, McGraw-Hill, New York, 1985

freely. Overdosing with coagulants can result in restabilizing the suspension. If enough ions are formed and adsorbed, the charges on the particles become reversed and the ionic clouds reform, with negative ions being the counter ions.

Sweep Coagulation

When metal salt coagulants are added at concentrations well above metal solubility a solid phase quickly develops. This solid phase is a metal hydroxide that forms amorphous, gelatinous flocs that are heavier than water and settle by gravity. Colloids may become entrapped in the flocs as they are formed, or they may become enmeshed by their surfaces as the flocs settle. This is referred to as sweep coagulation and can be highly dependent upon (2) pH.

Interparticle Bridging

Bridging mechanisms associated with polymers are complex and have not been adequately described analytically. (2) Schematically, when a polymer molecule comes in contact with a colloidal particle, some of the polymer chains adsorb at the particle surface, leaving the remainder of the molecule extending out into solution (Reaction 1 in Figure 5). The remainder of the polymer is available to adsorb on surface sites of other particulates, thus creating a "bridge" between the surfaces (Reaction 2 in Figure 5). If the extended polymer cannot find vacant sites on the surfaces of particulates, no bridging will occur and the

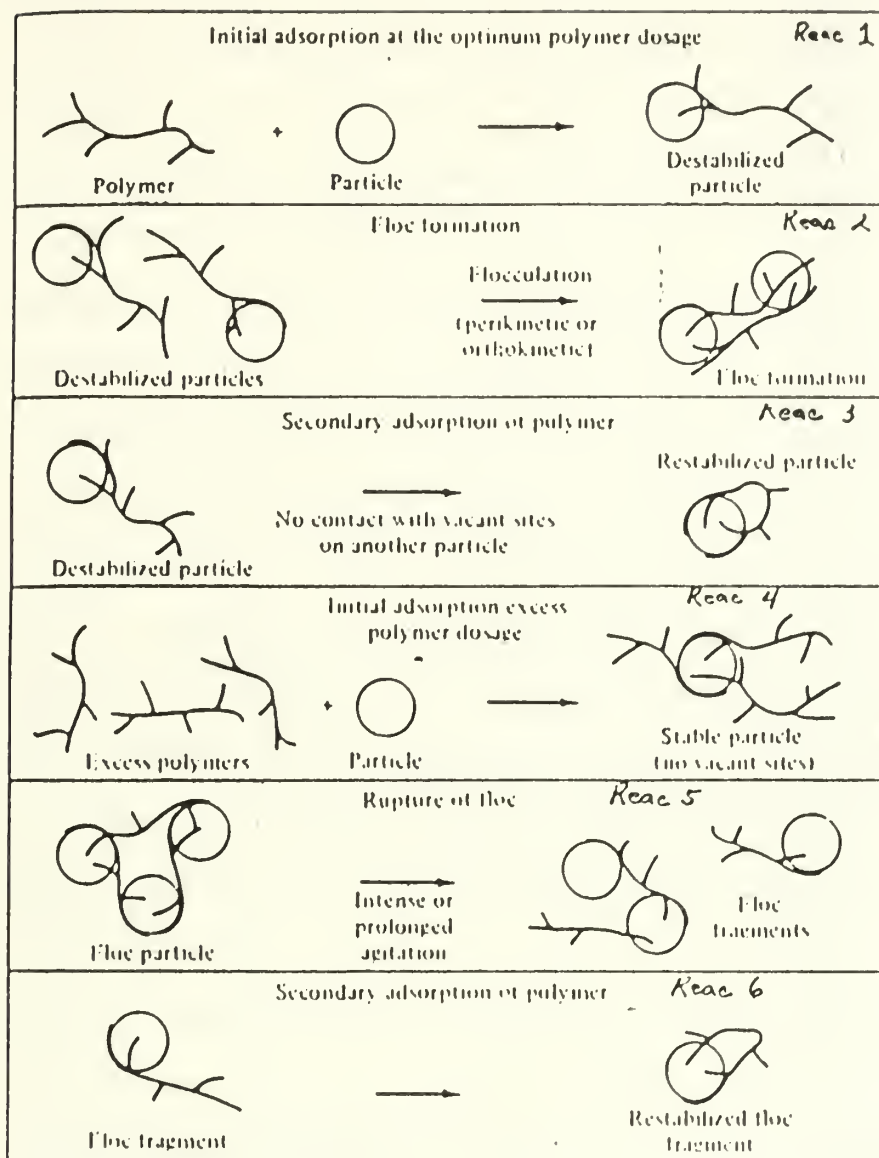


FIGURE 5: Interparticle bridging with polymers

Source: H. S. Peavy, D. R. Rowe, and G. Tchobanoglous, ENVIRONMENTAL ENGINEERING, McGraw-Hill, New York, 1985

polymer may eventually adsorb on other sites of the original particle, so that the polymer is no longer capable of serving as a bridge (Reaction 3 in Figure 5). Thus, there is a maximum degree of coverage or extent of polymer adsorption at which the rate of aggregation will be a maximum.

Because polymer bridging is an adsorption phenomenon, the optimum dose will generally be proportional to the concentration of particulates present. Dosages of polymer which are sufficiently large to saturate the colloidal surfaces produce a restabilized colloid, since no sites are available for the formation of interparticle bridges (Reaction 4 in Figure 5). Under certain conditions, a system which has been destabilized and aggregated can be restabilized by extended agitation, due to the breaking of polymer-surface bonds and the subsequent folding back of extended segments onto the surface of the particles (Reactions 5 and 6 in Figure 5).

Anionic, nonionic, and cationic polymers may function as bridging polymers; however, anionic and nonionic polymers are more widely used due to inherently higher molecular weights. Increases in molecular weight are advantageous because of the increase in polymer size and thus the potential extent of bridging. Solution properties (pH, ionic content) affect the polymer configuration in solution and at the interface. High ionic strength tends to cause the polymers to coil, thus decreasing their effectiveness.⁽¹⁾ Therefore, polymer selection requires extensive empirical testing.

Jar Tests for Optimum Coagulant Dosage

Coagulation is not yet an exact science. Therefore, selection and optimum dosages of coagulants are determined experimentally by the jar test instead of quantitatively by formula. The jar test must be performed on each water sample that is to be coagulated and must be repeated with each significant change in the quality of a given water.

The jar test is usually performed using a series of containers (of uniform size and shape) which hold at least 1 L of sample water. Normally, six jars are used with a stirring device that simultaneously mixes the contents of each jar with a uniform power input. Each of the six jars is filled to the 1-L mark with sample water whose turbidity and pH have been measured. Generally the test consists of a rapid mix phase (high mixing intensity) with simple batch addition of the coagulant or coagulants, followed by a slow mix period to simulate flocculation. After flocculation, the mixer is switched off and the flocs are allowed to separate from the water and samples of the clarified water are taken from the containers. Turbidity or suspended solids concentration can then be plotted as a function of coagulant dose.

In addition to performance, coagulant selection will depend on cost and the quantity and dewatering characteristics of the solids produced. Often, combinations of inorganic coagulants and polyelectrolytes provide the lowest-cost solutions to coagulation problems. (2) Because of the many available coagulant-polymer

combinations, a preliminary cost analysis is suggested to select viable combinations for jar testing. However, full-scale testing is usually required to refine the optimum coagulant combinations and doses because of the limits of the jar test in simulating the hydraulic conditions in full-scale facilities.

Coagulation Practices

Thorough mixing is essential if uniform coagulation is to occur. Consequently, careful attention must be paid to the design of rapid-mix units and flocculation units. Interparticle contacts, like particle destabilization, can be accomplished in several ways. As Brownian motion (perikinetic flocculation) is not usually effective, agitation (orthokinetic flocculation) is often used to increase particle interaction. In such systems the velocity of the fluid varies both spatially (from point to point) and temporally (from time to time). The spatial changes in velocity have been characterized by a parameter referred to as the velocity gradient, G . The velocity gradient is a measure of the relative velocity of two particles of fluid and the distance between. The velocity gradient should be optimized so that maximum particle interaction is attained while particle shearing is minimized to enhance the formation of large particles that exhibit rapid settling.

INITIAL WASTEWATER TREATABILITY STUDY

The initial study conducted by Old Dominion University

focused on analyzing the wastewater in the environmental engineering laboratories for ash removal by coagulation and sedimentation. The study was conducted in two phases. The first phase consisted of a characterization (pH, total suspended solids (TSS), and turbidity) of daily variability of the water samples. The second phase consisted of evaluation of individual coagulation aids for removal of the coal ash in these waters. The wastewater samples used during the study were taken daily for one week to ensure that a variety of coal ash conditions were evaluated. Samples of both top and bottom ash were used in the analysis. The four coagulant aids used during the study were alum, ferric chloride, anionic polymer, and a cationic polymer. The coagulant aids were added at various concentration levels in batch tests with a gang-stirrer set-up. Coal ash removal was quantified by turbidity measurements and was related to coagulant aid doses.

In this previous study ferric chloride and alum were equally effective for treatment of bottom water samples yet required high dosage levels compared to the polymers. However, the top samples treated with ferric chloride exhibited substantially poorer results when compared to the alum. Turbidity removal using the cationic polymer exhibited a negative relationship with dose, with the lowest turbidity measurements observed in samples receiving lower doses. This relationship suggests that at the higher polymer doses, "over-dosing" occurred. It was also observed that the cationic polymer was more effective at removing fly-ash (top sample) than the bottom ash. This is in contrast with the results

from the use of alum and ferric chloride. Overall, the cationic polymer was substantially effective for the top and bottom samples as long as the dose was in the range of 1 to 2 mg/l.

Additionally, the cationic polymer seemed to settle quicker than either the alum or ferric chloride. Suspended solids removal using the anionic polymer exhibited a negative correlation with coagulant dose very similar to that of the cationic polymer. The anionic polymer provided the highest degree of particle removal of all tests, with clarified NTU values less than 1 for polymer doses in the range of 1 to 8 mg/l. However, it was not as effective on the top samples as was the cationic polymer. Illustration of the coagulant dose-turbidity relationship for the four coagulant aids used in this study is contained in Appendix I.

It was determined that the anionic polymer displayed the best overall effectiveness and did not require any base addition (as with alum) to offset the polymer addition. Therefore, the anionic polymer was thus used in the follow-on treatability study.

FOLLOW-ON TREATABILITY STUDY

The purpose of this project was to further evaluate treatment of the wastewater from the Naval Amphibious Base Little Creek steam plant with regards to implementation of the anionic polymer. This study consisted of four phases. The first phase consisted of further characterization (pH, total suspended solids (TSS), total volatile solids (TVS), turbidity, ionic strength, and a chemical analysis) of the waste water. The second phase consisted of

evaluation of the anionic polymer's coagulation effectiveness with regards to pH changes in the wastewater. The third phase consisted of evaluating the effectiveness of the polymer with regards to variations in the velocity gradient during the flocculation process. The third phase of this project consisted of mixing the top and bottom wastewater samples in various proportions at a constant pH level and constant velocity gradient to analyze the effectiveness of the coagulant aid when top and bottom ash waters are mixed in various proportions before treatment. A description of the test methods is contained in Appendix II.

PHASE I: CHARACTERIZATION OF THE WASTEWATER

Water samples were collected on 25 February 1991 from the ash-silo at the Naval Amphibious Base Little Creek. It was noticed that the samples obtained by URS Consultants in January 1991 were obtained from a manhole approximately 70 yards northwest of the steamplant and that the manhole also had influent from two other sources. Therefore, it was decided to obtain the samples directly from the ash-silo to better assess the wastewater in question. The samples collected represent water containing fly ash (top samples) and water containing bottom ash (bottom samples). Appendix I contains the characteristics observed for the top and bottom water samples.

It was observed from the data that the bottom sample had both a higher pH (pH = 5.93) and a suspended solids concentration (TSS

= 2482) higher than the top samples (pH = 3.03, TSS = 515). There also appears to be a difference in the type of particles in suspension between the top and bottom samples - it was observed that the bottom sample had a "milky" appearance while the top samples were more black in color. The top sample had a significantly lower pH while the bottom samples displayed a much higher turbidity and contained significantly higher concentrations of total suspended solids. In addition, a visual inspection of the untreated water samples by microscope indicated that the particle size range of the top and bottom samples ranged from 15 μ m to 100 μ m with the bottom samples containing generally larger sizes and larger concentrations of particles. This relationship seems to reflect a greater proportion and greater concentration of larger particles in the bottom samples relative to the top samples. The chemical breakdown and conductivity analysis (see Table 1) of the top and bottom samples serve to reinforce the lower pH values of the top samples. Russell (1976) derived the following correlation between ionic strength and conductance of widely varying composition,

$$u = 1.6 \times 10^{-6} \times \text{specific conductance (in } \mu\text{mho/cm)}$$

This correlation was used to determine the ionic strength of the wastewater from the measured specific conductance, as shown in Table 1. As previously mentioned, solution properties (pH, ionic strength) affect the polymer configuration in solution and at the interface. High ionic strength (high conductivity) tends to cause the polymer to coil, thus decreasing the radius of gyration or

TABLE 1

	Top	Bottom
pH	3.03	5.93
TSS	515.3 mg/l	2482.6 mg/l
VS	0.3 mg/l	0.2 mg/l
Conductance	659 μ mho/cm	217 μ mho/cm
Ionic Strength	0.010544	0.003472
Turbidity (untreated)	204 NTU	720 NTU
Cl-	36.76 ppm	15.82 ppm
NO3-N	2.27 ppm	1.76 ppm
SO4--	225.24 ppm	72.43 ppm
Mn	17.0 ppm	17.0 ppm
Fe	1.15 ppm	0.8 ppm
Particle size	15 to 80 μ m	30 to 110 μ m

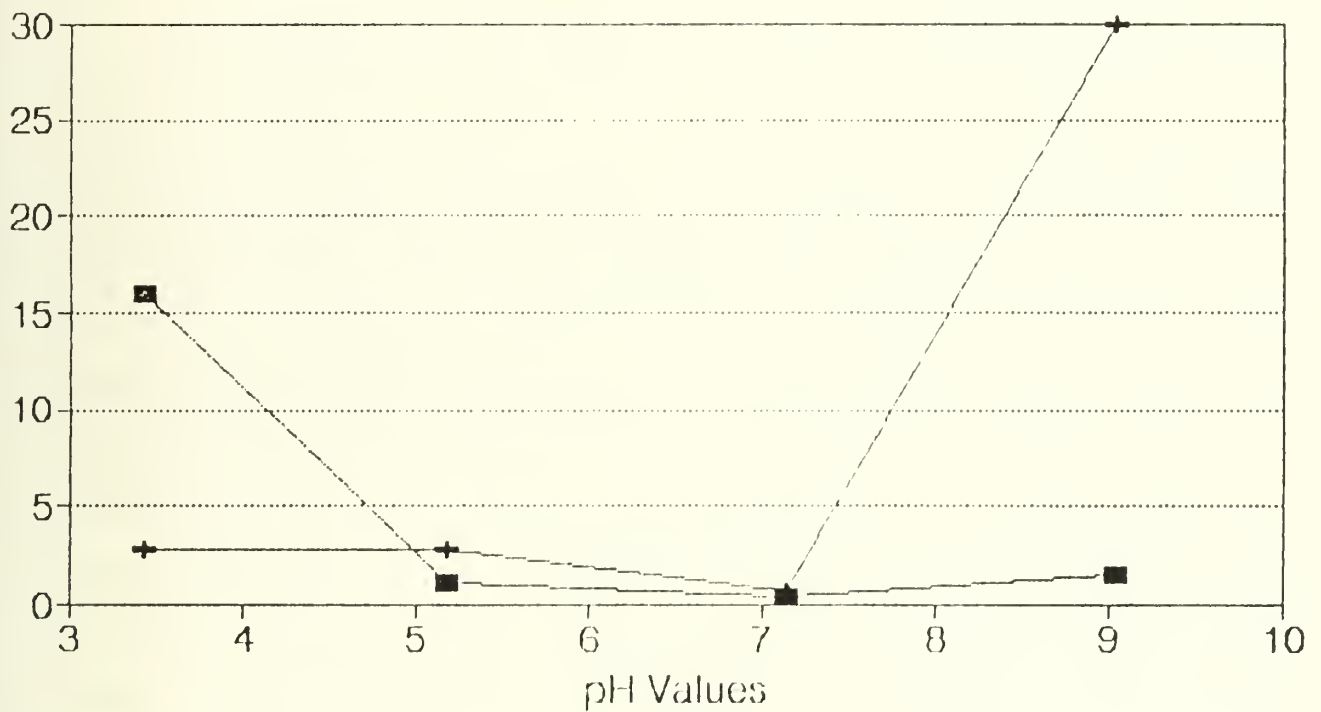
length of extension. Because of these complex interactions, polymer selection requires empirical testing. In addition, the top and bottom samples exhibited distinctly different characteristics, so the treatability studies were conducted on both top and bottom samples separately as well as with mixtures with varying proportions.

PHASE 2: EFFECTS OF VARYING pH

As it was determined that the wastewater from the ash-silo varied in pH with time, it was appropriate to analyze the effectiveness of the selected coagulant aid with regards to variations in pH for both the top and bottom samples. The anionic polymer displayed the best effectiveness for pH values ranging from 5.0 to 7.0 for both the top and bottom samples and that a dosage of 0.5 mg/l appeared to be the optimum dose when treating the top and bottom samples separately. In general, the trend for the top sample was that larger doses (2.0 mg/l) of the anionic polymer worked better than the other doses at the lower pH values. As the pH value for the top sample increased to around 7.0, the required dose of coagulant dropped to 0.5 mg/l. The effectiveness of the anionic polymer did appear to diminish with a further increase in pH to values around 9.0 and greater. For the bottom sample, the anionic polymer appeared to be more effective at the lower pH values than it did for the top. The trend for the bottom wastewater indicates a significant loss in effectiveness for all doses tested at pH values greater than 7.0. The results (Figure 6) graphically represent the effectiveness of

Figure 6: NTU vs pH

dosage: 1.0 mg/l



—■— Top Sample —+— Bottom Sample

the anionic polymer at a dose of 1.0 mg/l on the top and bottom samples - it is apparent that it loses effectiveness at low pH values (less than 5.0) on treating the top sample yet significantly loses effectiveness on the bottom sample at pH values greater than 7.0. Similar results were obtained with dosages of 0.5 mg/l and 2.0 mg/l for both top and bottom samples.

PHASE 3: EFFECTS OF CHANGING VELOCITY GRADIENT IN FLOCCULATION

It is important to promote particle aggregation for colloidal particles and to optimize flocculation rates through mechanical mixing. The impacts of various velocity gradients on flocculation and removal of coalash were analyzed; methods for this phase of analysis are contained in Appendix II and the test data is contained in Appendix III. The test data (see Figures 7 and 8; dosage of 0.5 mg/l is representative of effect of other concentrations for top and bottom samples) indicate an increase in removal efficiency for all dosages being considered (for both the top and bottom samples) with increased velocity gradient over the range tested. Figures 9 and 10 graphically represent the results of using a velocity gradient of 80/sec for both wastewaters. In addition, the optimum dosage appears to be 0.5 mg/l in both cases. From a visual analysis, the size of particles associated with the tests run at 80/sec were smaller than those of lower velocity gradients. Therefore, it is apparent that although the increased power applied decreases particle sizes due to increased shearing,

Fig 7: VELOCITY GRADIENT ANALYSIS

Top Sample, pH = 7.01, dosage = .5 mg/l

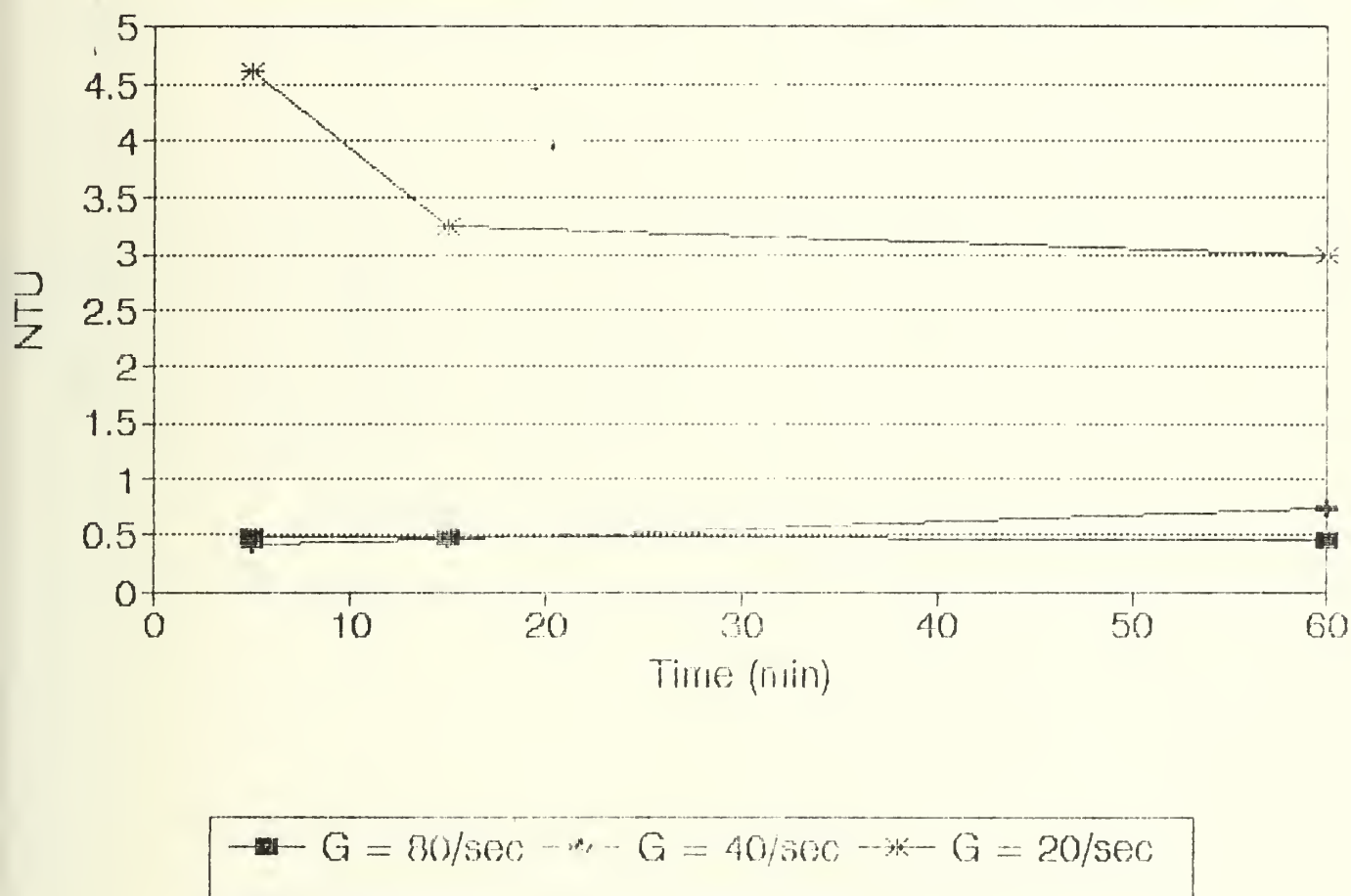


Fig 8: VELOCITY GRADIENT ANALYSIS

Bottom Sample, dosage = .5 mg/l

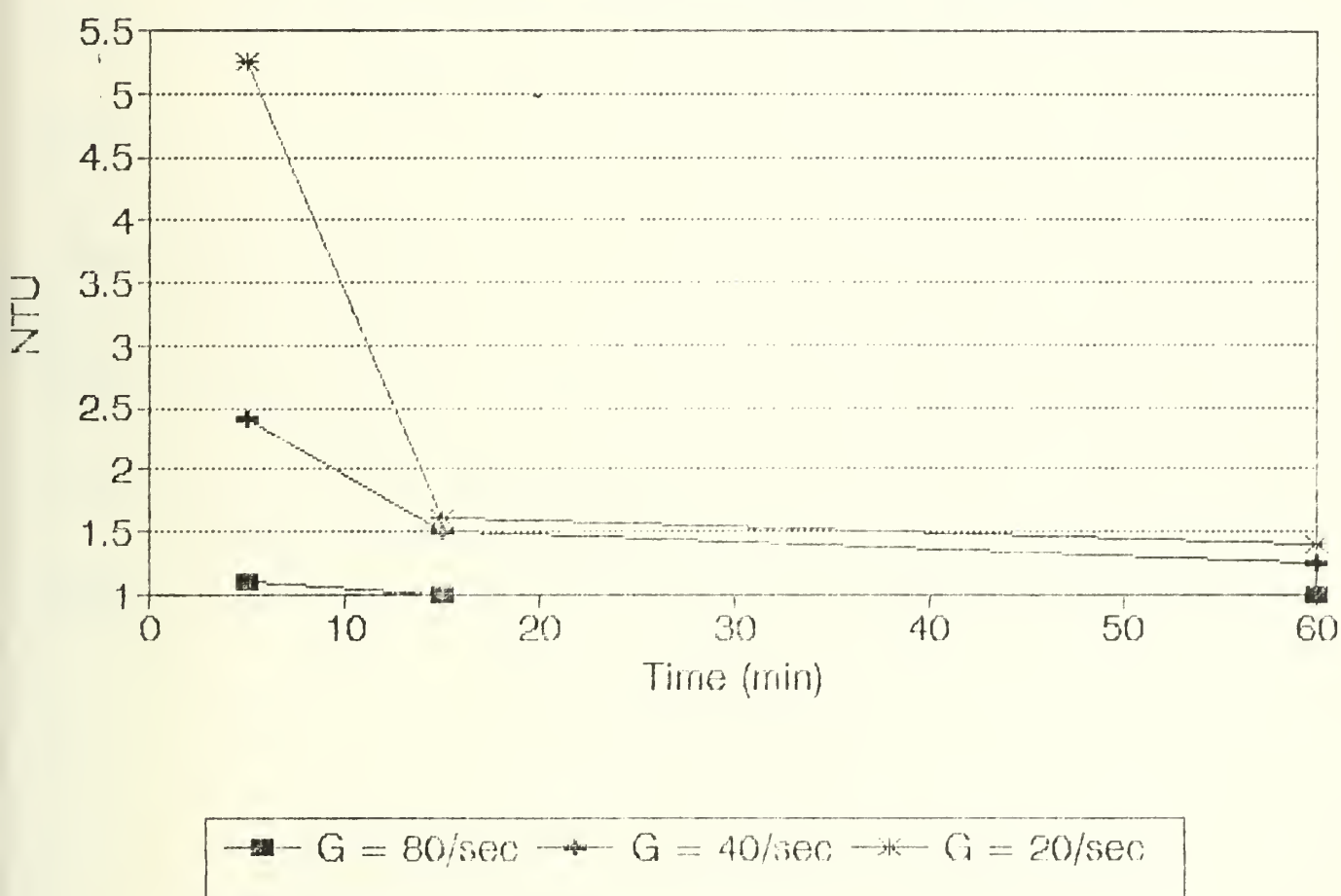
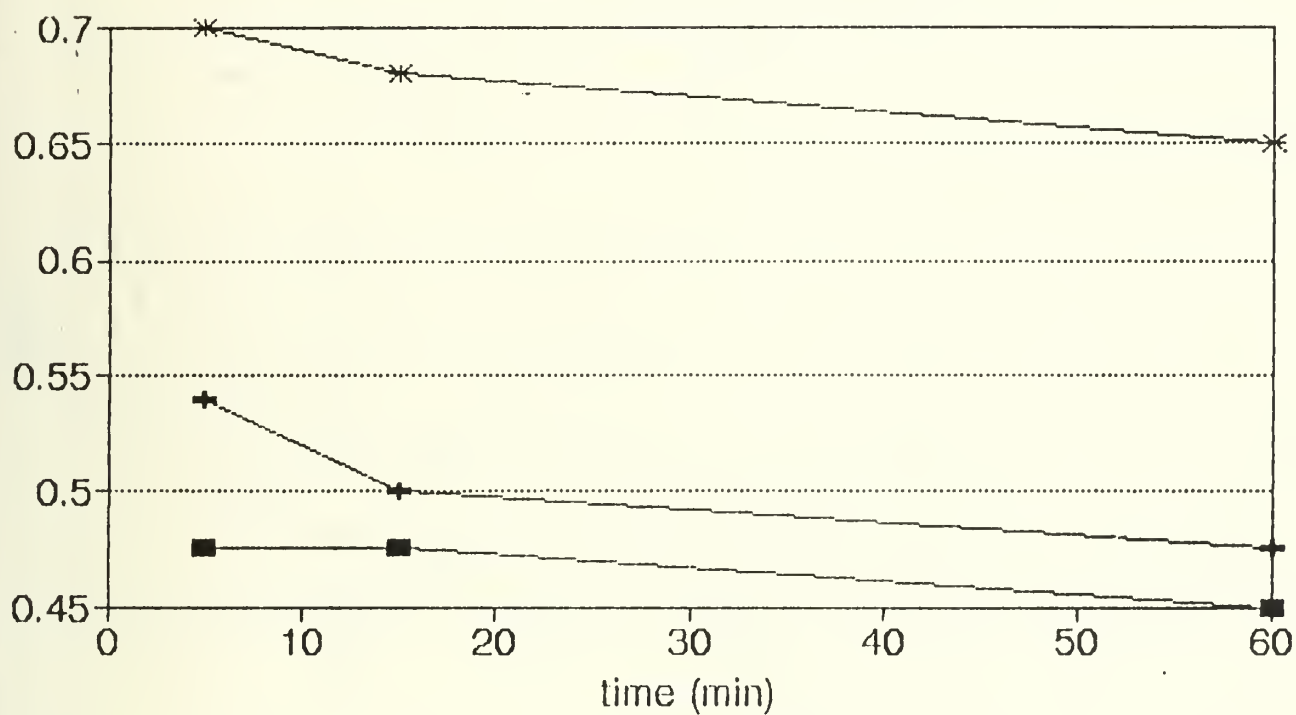
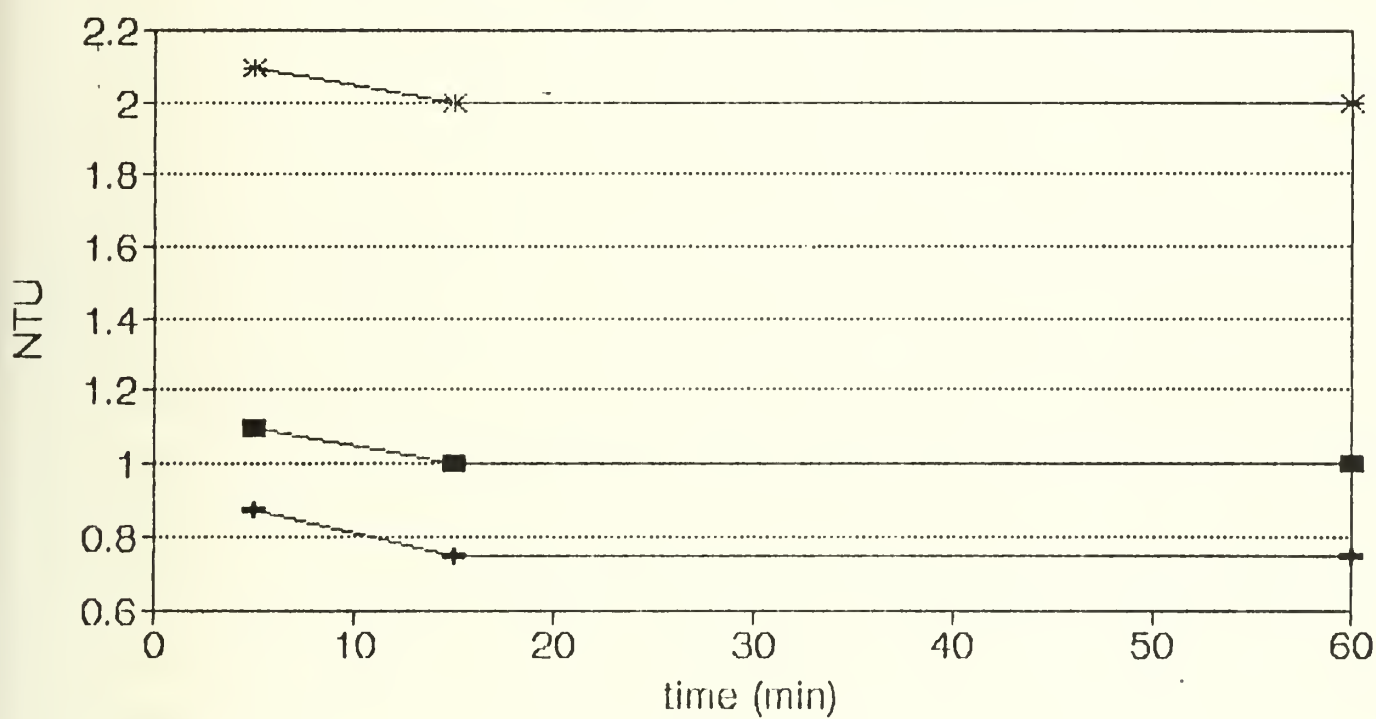


Figure 9: TEST #9
TOP SAMPLE, $G = 80/s$, $pH = 6.97$



—■— 0.5 mg/l —+— 1.0 mg/l —*— 2.0 mg/l

Figure 10: TEST #12
BOTTOM SAMPLE, $G = 80/s$, $pH = 7.0$



—■— 0.5 mg/l —+— 1.0 mg/l —*— 2.0 mg/l

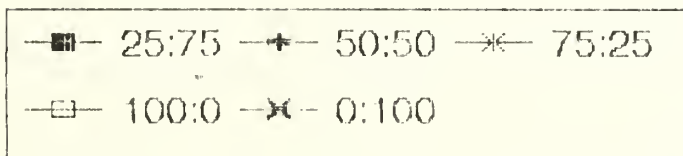
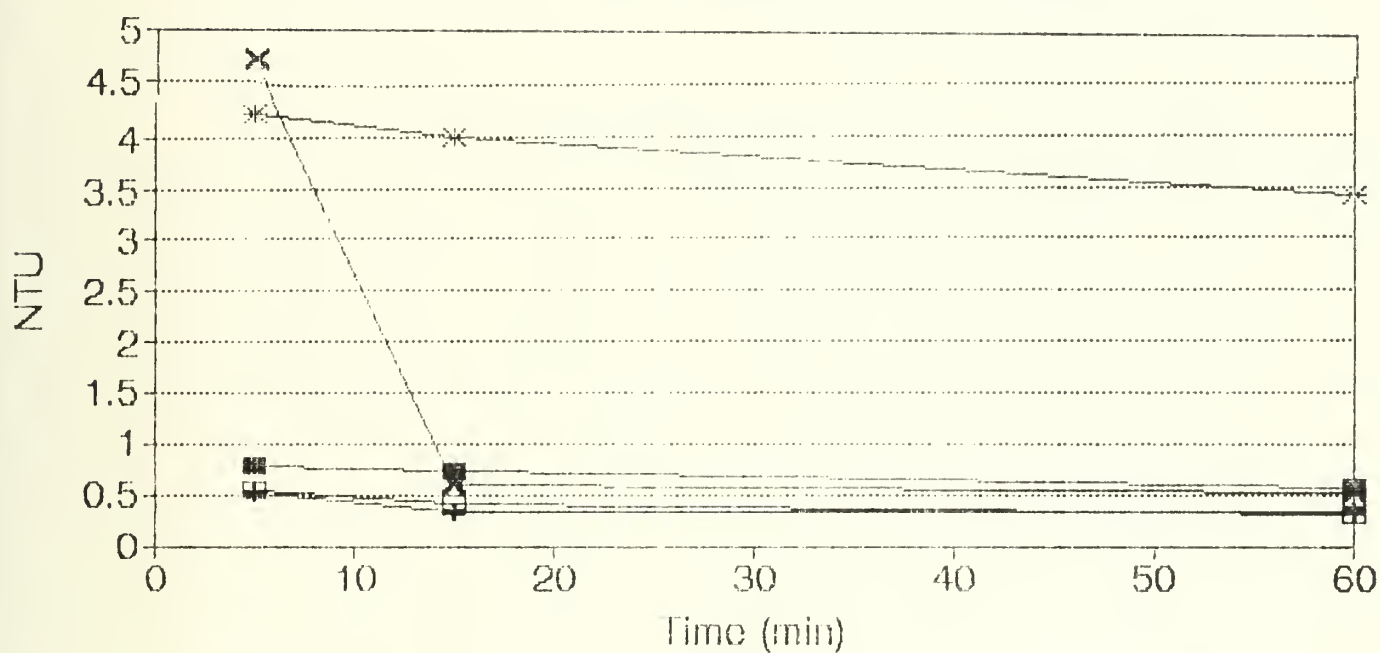
there is an increase in particle interaction thereby increasing the removal effectiveness of the coagulant aid.

PHASE 4: EFFECTS OF VARYING WASTEWATER MIXTURES

The flow of wastewater from the ash-silo is such that approximately 30 gpm for approximately 15 minutes is the top sample followed by a 5 to 10 minute lull (no flow) and then a 15 to 20 minute period of bottom-ash wastewater flow. As such, a continuous flow type operation may not be economically feasible. Therefore, a holding tank to receive all of the wastewater from a draw-down evolution and then treat this wastewater as a bulk mixture may be possible. Therefore, the wastewater was analyzed in top to bottom ratios of 0:100, 25:75, 50:50, 75:25, and 100:0, which would represent the range of possible mixtures, for a standard pH value of 7.00. Figure 11 graphically represents the results of the analysis for a coagulant dosage of 0.5 mg/l. It is evident that when comparing the mixtures of 25:75, 50:50, and 75:25, as the amount of top sample is increased in the mixture, the effectiveness of the coagulant dose decreased. However, at a 100% solution of top sample, the dosage appears to be quite effective. In addition, the dosage is moderately effective on the 0:100 mixture. Apparently there is a reaction taking place between the top and bottom samples which reduces the effectiveness of the coagulant aid. The determination of the reaction taking place is beyond the scope of this report.

Figure 11: TOP : BOTTOM RATIOS

dosage = 0.5 mg/l $G = 20/s$



DISCUSSION AND SUMMARY

Based on the test results, it is determined that the anionic polymer is most effective for the wastewater being tested. A dose of 0.5 mg/l is recommended for a pH adjusted to approximately 7.0 and with a velocity gradient for flocculation of 80/sec. As the wastewater flow from the ash-silo is approximately 30 gpm for a duration of roughly 15 minutes for the top and 15 minutes for the bottom draw-down evolutions, a continuous flow system could be utilized.

Use of the anionic polymer with a flash mix/flocculation module of an inclined plate separator is an option for treatment of this wastewater. This would allow for the removal of the coal ash as a sludge. Package unit separators are available with various features from sludge thickeners, to reduce the amount of coal-ash, automatic chemical addition systems, which add the proper dosage of the polymer, automatic pH adjustment systems, and separator covers, to keep out rain and dust particles. Cost of inclined plate separators would be in the range of \$50,000 to \$75,000 - not including equipment installation costs. Similar systems are currently being used by large coal burning power producing facilities throughout the country.

Some advantages to wastewater treatment include :

- the existing coal ash removal system would not require upgrading
- the coal ash can be successfully removed without involving a labor intensive process

- the cost of the unit is reasonable low

Some disadvantages of wastewater treatment include:

- maintenance of the unit
- purchase and resupply of the coagulant aid
- removal and disposal of the coal ash sludge
- pipe alterations to the ash-silo wastewater discharge system would be required to to install the equipment

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A P P E N D I X I

INITIAL STUDY TEST DATA

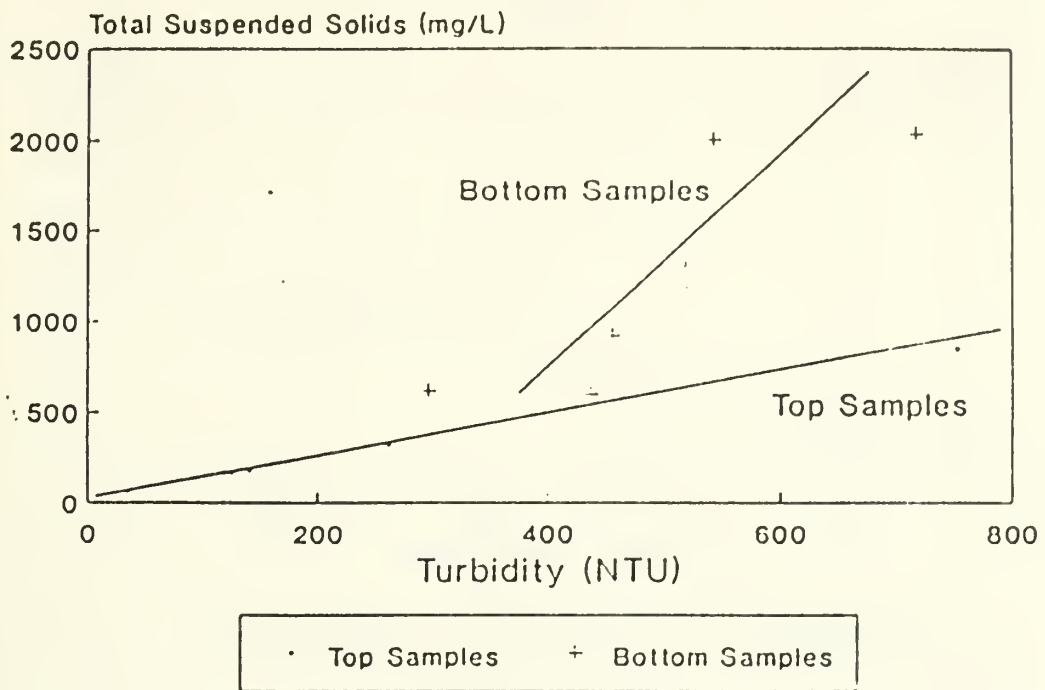


FIGURE 1.

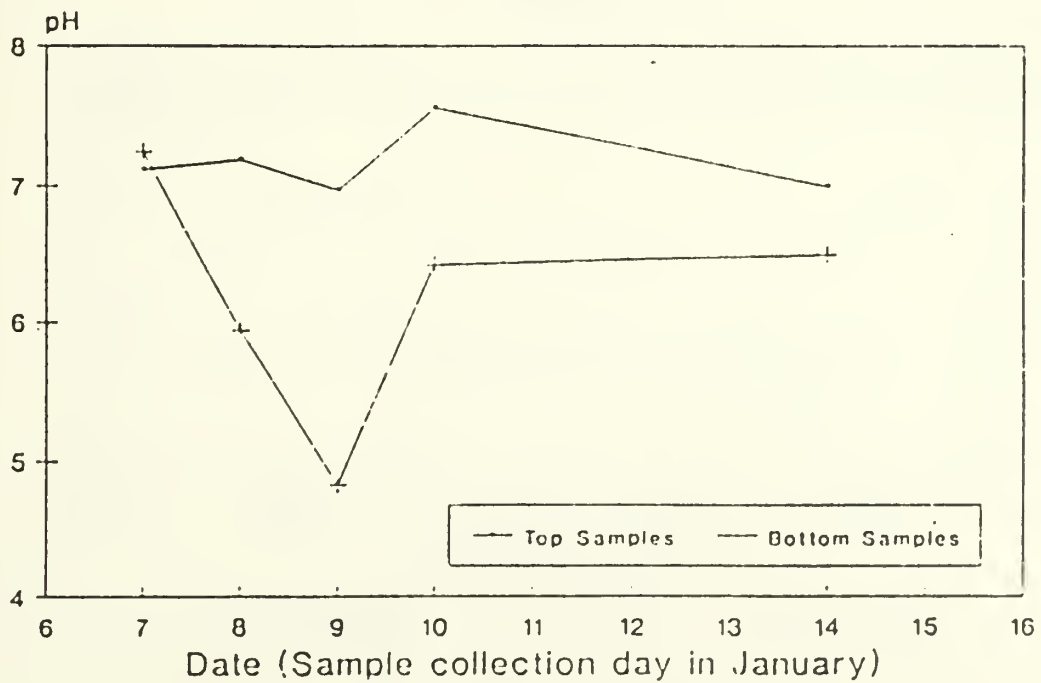


FIGURE 2.

Fly Ash Removal Utilizing Alum

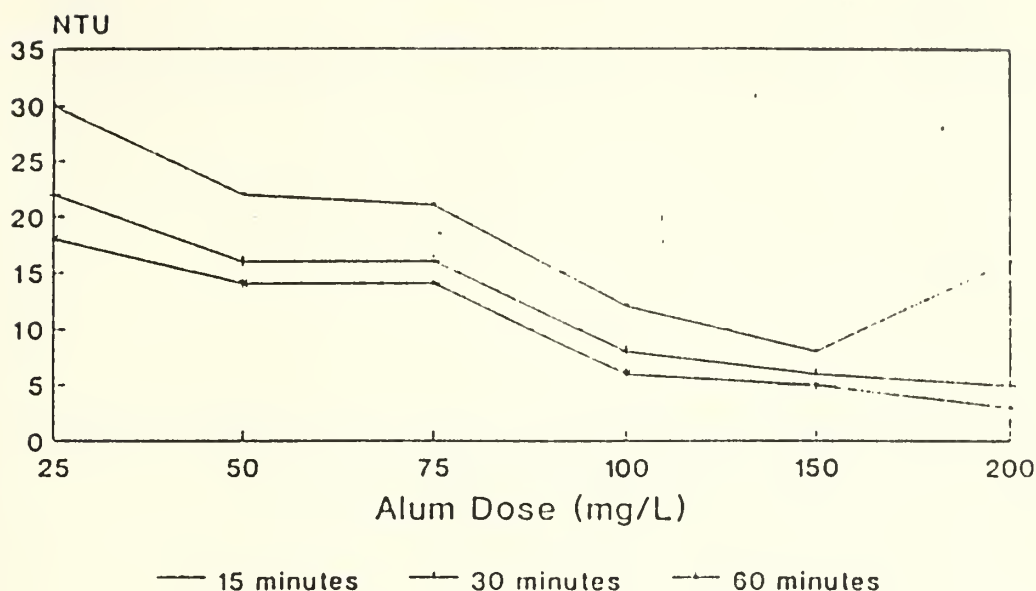


FIGURE 3A.

Bottom Ash Removal Utilizing Alum

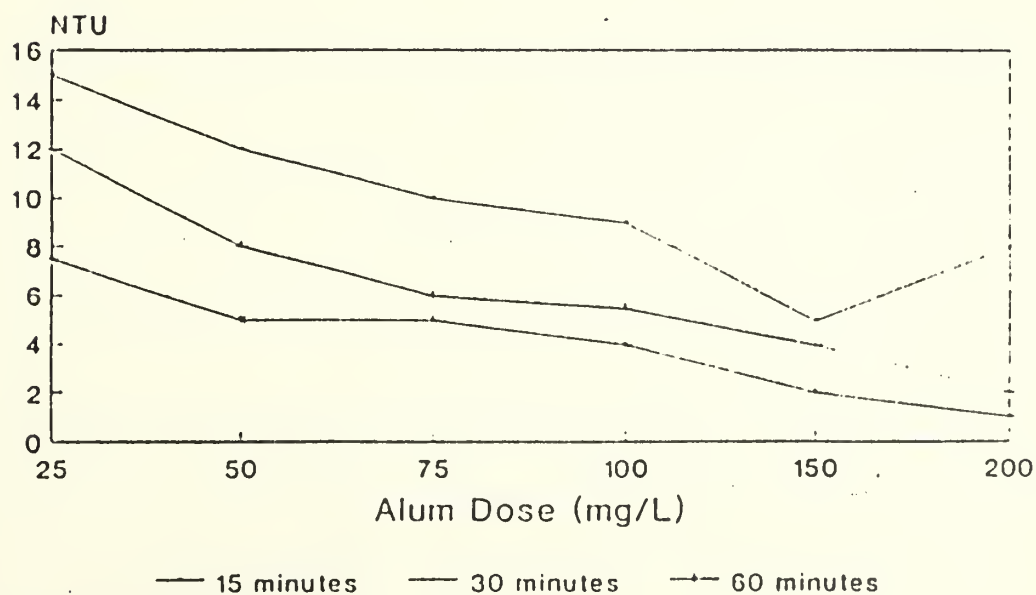


FIGURE 3B.

Fly Ash Removal Utilizing Ferric Chloride

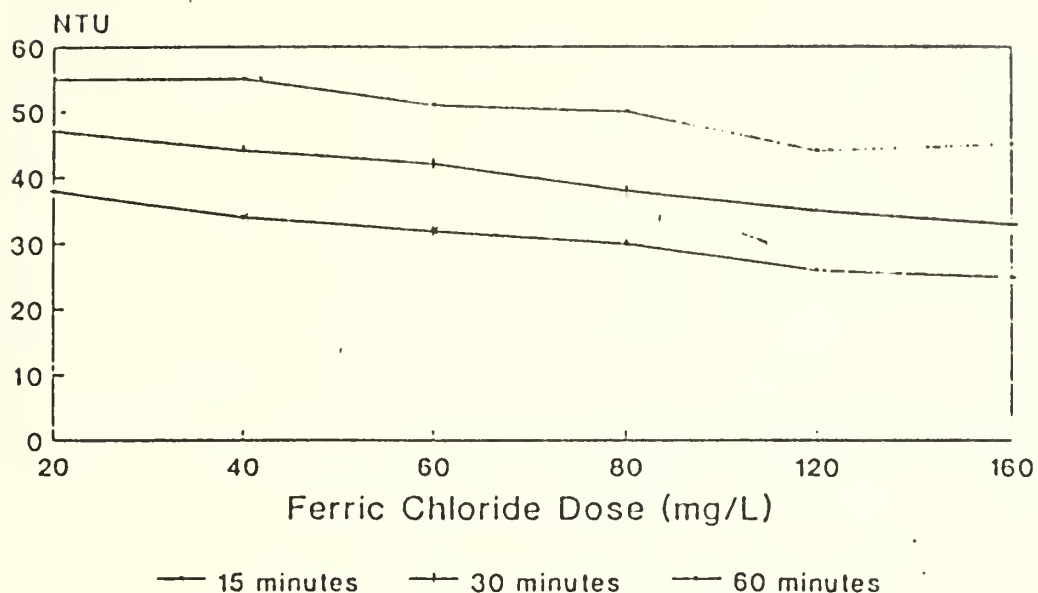


FIGURE 4A.

Bottom Ash Removal Utilizing Ferric Chloride

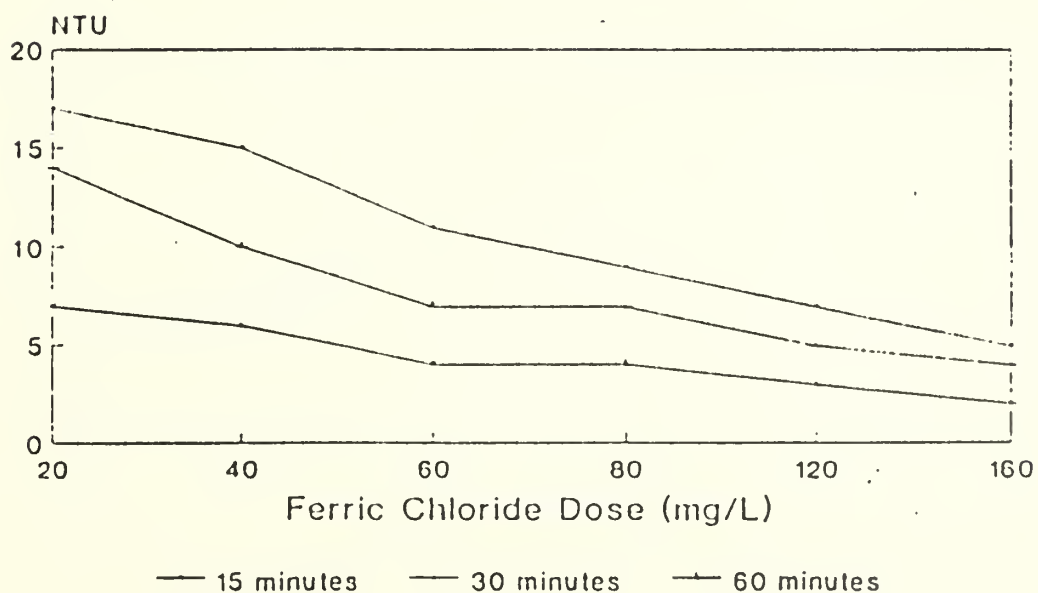
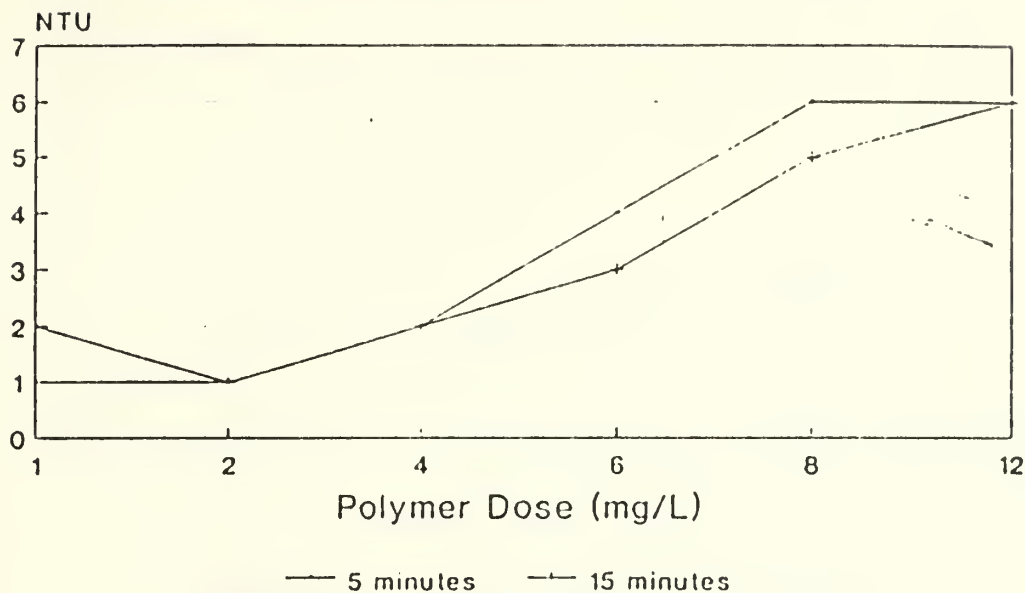


FIGURE 4B.

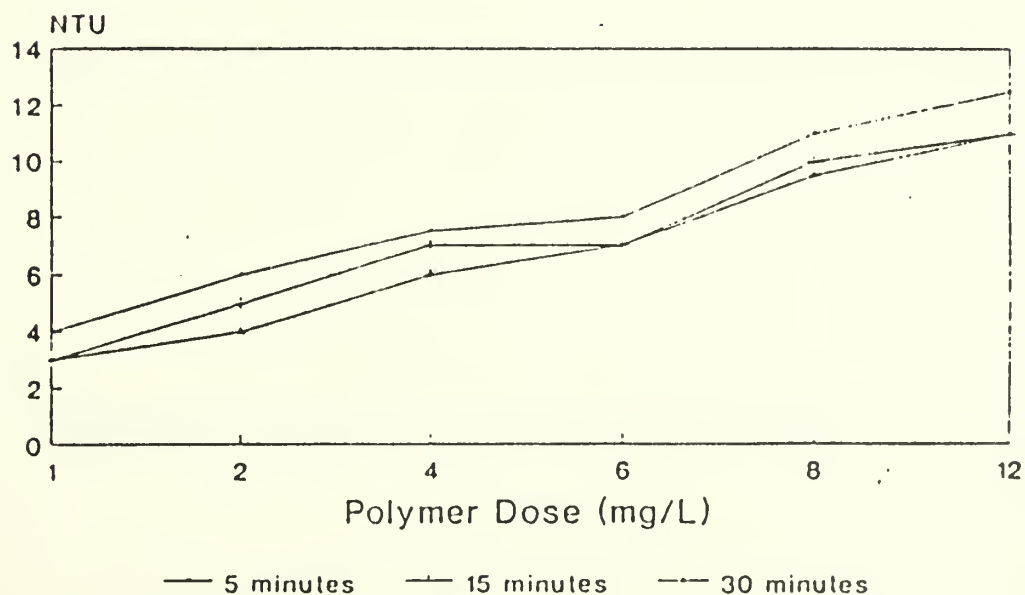
Fly Ash Removal Utilizing Cationic Polymer (Percol 763)



Percol 763, Allied Colloids

FIGURE 5A.

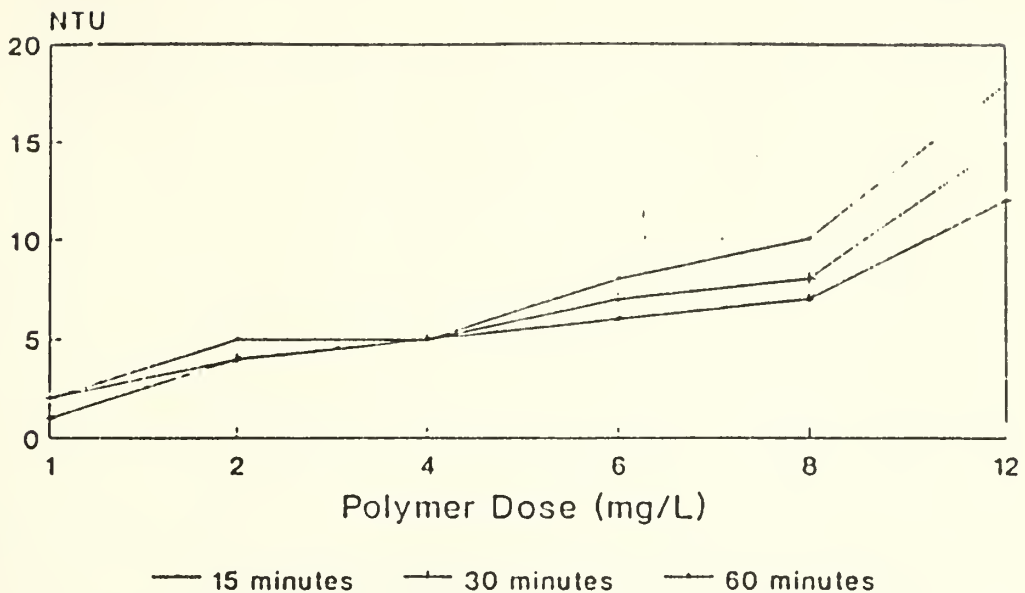
Bottom Ash Removal Utilizing Cationic Polymer (Percol 763)



Percol 763, Allied Colloids

FIGURE 5B.

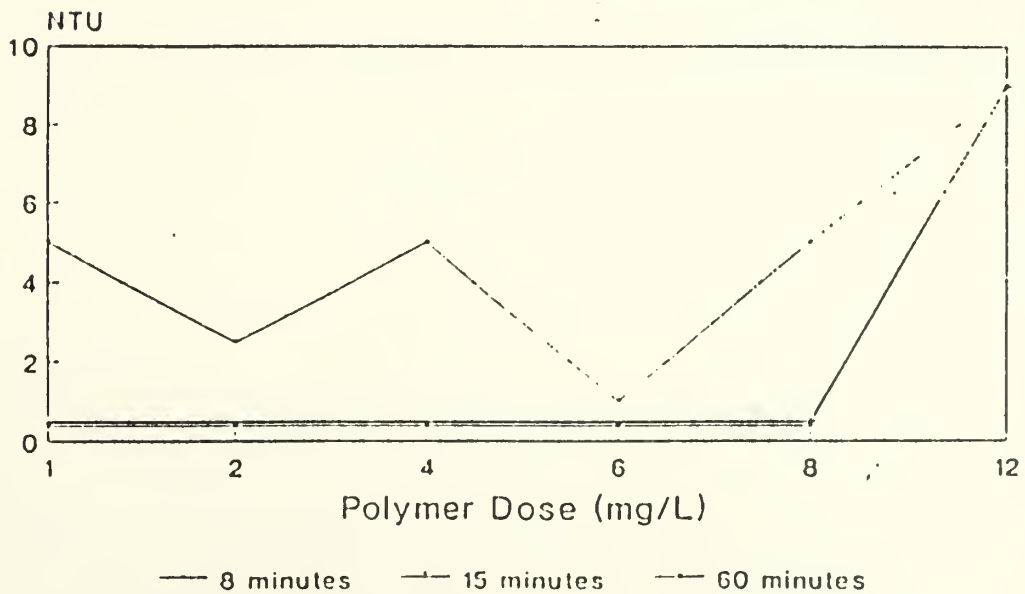
Fly Ash Removal Utilizing Anionic Polymer (Percol 727)



Percol 727, Allied Colloids

FIGURE 6A.

Bottom Ash Removal Utilizing Anionic Polymer (Percol 727)



Percol 727, Allied Colloids

FIGURE 6B.

A P P E N D I X II

APPENDIX II: METHODS

Phase I: Wastewater Characterization

Tests for determining the pH of the wastewater samples were conducted using an Orion Research Digital pH/millivolt meter, Model 611. Calibration of the equipment was conducted using stock pH solutions of 7.0 and 4.0.

Turbidity measurements of the untreated samples were conducted using stock turbidity solutions of 400 NTU, 40 NTU, 4.0 NTU, and 0.4 NTU prepared per the procedures outlined in the Standard Methods For The Examination of Water and Wastewater, 14th edition. Equipment calibration and operation was conducted per the owner's manual.

The tests for determining the Total Suspended Solids and Total Volatile Solids were conducted per the Standard Methods For the Examination of Water and Wastewater, 14th Edition. The filters used were Reeve Angel fiber glass filters, 5.5 cm thick, grade 934 AH. The weigh dishes were aluminum weigh dishes, 75 mm, by Fisher Products.

Jar Test Operation

Phase 2:

Jar tests were conducted by initially pouring 10-liter of top sample into a reactor. Then, 3 liters of sample were removed and placed in 3 standard jar test reactors (1-liter each) and then placed on the gang stirrer. The main reactor sample was then

agitated and the pH value of the sample was adjusted (by addition of NaHCO_3) to a value of approximately 5.0. After this step, 3-liters of sample were removed and placed in 3 standard jar test reactors (1-liter each). These three reactors were then placed below the gang stirrer and the stirrer was turned on to a speed of approximately 250 rpm to agitate the samples while the coagulant aids were added (flash-mixed). These six reactors were then flash mixed for approximately 1 minute. After flash-mixing, the gang stirrer was slowed to approximately 15 rpm for 5 minutes. Then the mixer was turned off and the particles were allowed to settle. Approximately 32 ml samples were drawn from each reactor at 5, 15, and 60 minute intervals through a tube connected through the side of each reactor. The tube opening in the side of each reactor was located 5 cm above the bottom of each reactor and allowed the removal of clarified water with minimal disturbance of the reactor and its contents. Each 32 ml sample was then immediately measured for turbidity using a Hach Model 2100A Turbidimeter that was calibrated daily (to the range desired for each sample) with standard solution of hexamethylenetetramine, hydrazine sulfate suspension. Then, the sample in the main reactor was adjusted to a pH value of approximately 7.0 and 3 1-liter reactor samples were placed on the gang stirrer, followed by 3-liters of sample adjusted to a pH of approximately 9.0. These samples were flash-mixed, flocculated, and settled as above with turbidity measurements taken. The above process was repeated again using 10 liters of bottom sample (except that the sample was initially lowered to a pH value of approximately 3.0 using nitric acid).

Phase 3:

Jar tests were conducted by initially pouring 10 liters of top sample into the main reactor and adjusting the pH value of the sample to approximately 7.0 (by adding NaHCO_3). After pH adjustment, 3 1-liter volumes were measured out and placed in standard jar test reactors. These reactors were then placed below the gang stirrer and the stirrer was turned on. The samples were flash-mixed for 1 minute at 250 rpm while the anionic polymer was added to each (doses of 0.5, 1.0, and 2.0 mg/l). Following flash-mixing, the samples were flocculated for 5 minutes at an rpm of approximately 75 rpm, after which the mixer was turned off and the particles allowed to settle. Approximately 32 ml samples were withdrawn from each reactor at 5, 15, and 60 minute intervals and immediately measured for turbidity using a Hach Model 2100A Turbidimeter. Three liters of sample from the main reactor were then tested as before using a flocculation speed of 46 rpm and measured for turbidity followed another 3 liters of sample at a flocculation speed of approximately 26 rpm. All of the above was then repeated for 10 liters of bottom sample.

Phase 4:

Jar tests were conducted by initially pouring 3 liters of sample (at a mixture of 75% top sample to 25% bottom sample) into a reactor and adjusting the pH value of the mixture to approximately 7.0 (by adding NaHCO_3). After pH adjustment, 1-liter volumes were measured out and placed in standard jar test reactors. The reactors were then placed below the gang stirrer and the stirrer was turned on to approximately 250 rpm for flash

mixing for 1 minute while the coagulant aid was added in 0.5, 1.0, and 2.0 mg/l doses. The flash-mix period was followed by a 5 minute period of flocculation at approximately 25 rpm, after which the mixer was turned off and the particles were allowed to settle. Approximately 32 ml samples were withdrawn from each reactor at 5, 15, and 60-minute intervals. These samples were then immediately tested for turbidity. The above tests were repeated for samples of 50% Top/50% Bottom and 25% Top/75% bottom with turbidity measurements taken for each.

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Thesis

S4166 Sellers

c.1 Optimization of suspended solids removal from coal-ash laden wastewaters.



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